CAR LUBRICATION.

BY

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PREFACE.

SOME years ago the subject of car lubrication became one of much interest to the writer, and, when attempting to acquaint himself with the laws influencing successful practice, he was surprised to find how very little information, either of a theoretical or practical nature, could be obtained. The accompanying pages are not presented as a solution of the question, or as containing any important original research, but rather in the hope that some of the knotty problems which were then presented for solution may be made clearer.

The laws of friction, as accepted until recently, have by later experiments been limited in their application, if not confined entirely, to solids in contact. It is at least certain that they will not apply in any way as the laws governing the friction of solids separated by a lubricant. Prof. Thurston's "Friction and Lost Work," and the experiments of Mr. Woodbury with those of Mr. Tower, are quoted, and several others to a limited extent—to whom, it is hoped, proper credit has been given.

It is desired that these few words may stimulate further thought, and in that way result in a more satisfactory solution of the problem.

THE AUTHOR.

ALTOONA MACHINE SHOPS, May, 1891.

CAR LUBRICATION.

CHAPTER I.

INTRODUCTION.

THE subject of car lubrication is wholly dependent upon the conditions which influence friction, either increasing or decreasing the resistance according to the design and proportions of the different parts, as well as by the care and attention which are given to the lubrication proper. There is hardly any other one branch of railroad engineering so dependent upon empirical laws, and but few where the heretofore accepted laws of friction are at such variance with practice.

The widely taught law that friction is independent of the extent of surface in contact, but varies only with the pressure, is about ready to be placed among the archives of ancient scientists. The pressure inferred in this relationship is that exerted over the whole surface, and not per square inch—that is, a surface one square foot in area exerting a pressure of one pound per square inch would require the same force to move it over a rubbing surface as it would if made of one square inch in area exerting a pressure of 144 pounds per square inch. The extent of surface in contact was supposed to have no effect upon the force or work of friction necessary to move one body upon another, and consequently

required no increased effort to produce motion, provided the same total pressure was exerted although the area of the surfaces in contact might be at variance.

Recent investigations upon the friction of lubricated surfaces, made with the object of determining the laws governing the coefficient of friction with various grades of lubricants, have shown the contrary to be more like the true conditions than those previously stated. If the relationship of the "resistance of friction as independent of the area of surfaces in contact, but dependent upon the pressure," were true, the temptation would be to reduce the work of friction and the abrasion of the materials by an increase of the length and diameter of the journal.

Practical demonstration, however, has proved the necessity of avoiding long journals; while, with the friction of rotation, an increase in the diameter of the journal means a corresponding increase in the work of friction. These investigations have given results which will be found to accord quite closely with those obtained from practice, and at the same time have given information of much value for guidance in the construction and management of lubricated surfaces where motion is present. They indicate, and quite conclusively, that friction is, when the rubbing surfaces are kept well separated by the lubricant, more dependent upon the nature and fluidity of the lubricant than upon the nature of the solids carrying the load.

There seems to be a combined friction consisting of that inherent in the particles forming the lubricant and of the moving surface in contact with it. With constant pressure and temperature, it is dependent upon

the extent of surface in contact and varies directly with it. It is also influenced by the unit pressure, and varies directly with some ratio of the change in the load, but not in the same ratio as had been previously supposed.

As the resistance of lubricated surfaces is made up of the resistance of the particles of the lubricant, it is evident that any influence that will change its fluidity will also affect the frictional resistance.

Increase of temperature, increasing the fluidity, causes a decrease in the coefficient of friction; while increase in unit pressure causes an increase in the density of the fluid, and, necessarily, an increase in the friction when motion is produced.

The condition to be attained is that where the viscosity of the oil is such at the working temperature that it will be sufficient to keep the solids from contact under the pressure which must be sustained.

The convincing point which should be kept in mind is the fact that frictional resistance and the abrasion of the surfaces is a representation of an expenditure of money, and of an amount greater than is generally supposed. The object of the following chapters will be, pure and simple, to reduce the conditions to a relationship the nature of which will assist towards reducing this expenditure, either directly or indirectly, to the lowest attainable figure.

The problem will be treated in the following order:

1st. The proportions and materials which are required to meet the demands of the service.

2d. The most economical way in which these may be applied.

CHAPTER II.

THEORETICAL RELATIONS.

THE resistance of friction in car lubrication is that which is generally known as "sliding friction of rotation." It is similar to linear motion, but, as it is an arc of contact, it differs in the distribution of the load per unit of surface.

When the bearing is first placed upon the journal the arc of contact is small, and it is only after wear has taken place that the whole arc included within the bearing is in contact with the journal. The amount of wear which is necessary to produce this condition is very small unless the radius of the bearing is made much larger than that of the journal, which must be classed as bad practice.

It will be found that the greatest amount of the pressure is taken at the top of the journal, and decreases in a determinable ratio from that to the horizontal axis through the centre of the journal. The work of friction is then but a question of the space which is passed over against the frictional resistance which is offered to the rotation. The space in this case is a function of the circumference, and varies as the diameter of the journal.

The law of the distribution of the pressure is as follows;

Let (see Fig. 1)

P = unit vertical pressure;
P_1 = unit pressure in a radial direction;
R = radius of the journal;
ω = angle made by the radius from a point O with a vertical line through the centre of the journal;
l = length of bearing;
L = total load carried.

For any point, O,

$$P_1 = P \cos \omega.$$

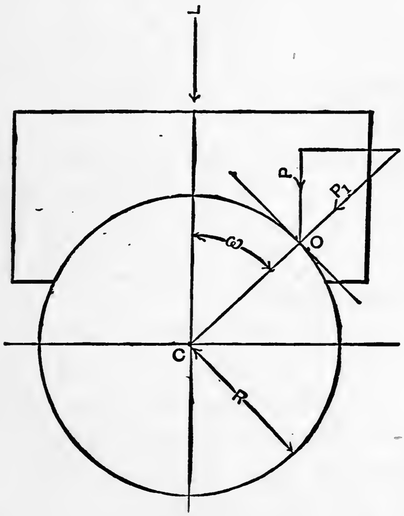

FIG. 1.

The pressure upon a surface $Rd\omega$ is

$$P_1 lRd\omega.$$

The summation of the pressure should be for an equal arc on each side of the vertical, or

$$L = \int_{-}^{+} P_1 lR d\omega;$$

and by inserting the value of P_1,

$$L = \int_{-}^{+} PlR \cos \omega \, d\omega.$$

From this, the load carried by various arcs subtended can readily be obtained. The accompanying table will indicate the values for several values of ω. It will also allow a comparison of the value of the pressure upon a 20° arc for higher values of ω.

Value of ω.	Average pressure carried per square inch.	Square inches of surface when radius equal unity.	Percentage carried by the first 10° of the arc.
10°	0.34729	0.1745	100.00
20°	0.68404	0.3490	50.78
30°	1.00000	0.5235	34.73
40°	1.28558	0.6980	27.01
50°	1.53209	0.8725	22.67

It is then evident that more of the pressure is taken by a small arc of the journal, and that the lower surface of the arc of contact figures as a less important part of the distributing surface for the load. It would then appear that if the bearing had a surface contact of 3.5 inches when the journal is four (4) inches in diameter, there would be very little cause of trouble arising from too high a unit pressure. It would also follow that the practice of boring out the bearing to a greater radius than the journal is open to no serious objection, providing the difference in the radii is not made too great. When this is done a condition similar to that shown in

Fig. 2 results. The sharp corners at A have a tendency to scrape the oil from the journal, and in that way give trouble. This effect will be more apparent further on. The condition shown in Fig. 2 will result in very poor lubrication, and likely produce a heated journal. In practice it is found that good results are obtained when the bearing radius is about one thirty-second ($\frac{1}{32}$) of an inch more than the radius of the

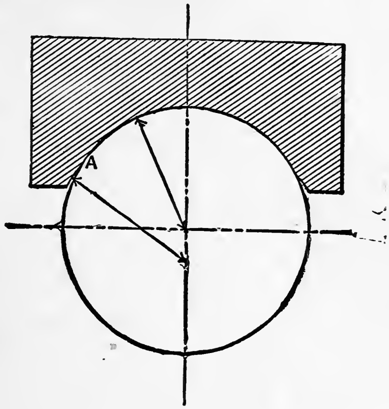

FIG. 2.

journal. This gives a safe working margin for a new bearing and journal. The difference in the radii becomes greater when a new bearing is placed upon a worn journal. The detrimental effect which arises with a too large difference between the arcs of the two parts is overcome by lining the bearing with a soft metal of about one sixteenth ($\frac{1}{16}$) of an inch in thickness.

Before stating the elements determining the work of friction, it is necessary to review in a general way the results of recent experiments which were made to de-

termine the laws governing the resistance to motion of bodies when separated by a lubricant. The reference is particularly to the experiments by Woodbury and Tower, the results from both of which, while made under different conditions, are corroborative. Those by Woodbury were made with low pressures, and the curves obtained from his results give a relationship of pressure and coefficient of friction, as shown in the diagram, marked as Fig. 3. They prove quite conclusively that friction is not a direct ratio factor of the pressure as it is with solid surfaces; but, on the contrary, the laws seem to follow those of fluid friction more closely than those of solids. The result produced by the motion of two solids under pressure is a more or less rapid abrasion of the metals in contact. With a lubricant interposed, the conditions are quite changed and follow more closely the resistance which the fluid would offer by its own friction. Whether or no this be a motion of the particles of the lubricant or of the solid upon the surface of the fluid matters not here. The important consideration is the extent of surface in contact which should enter as an element in the calculation of the work done. The friction should represent the resistance of the lubricant at the pressure carried, reduced to the resistance under these conditions for a unit surface. The resistance of friction would then consist of two elements: the coefficient of friction per unit of surface for the working pressure and temperature, and the number of units of surface in contact. Representing these by f and a, respectively, would give as the relationship of the total work of friction

$$W = f \cdot a \cdot p \cdot 2\pi R \times n,$$

where

$n =$ number of revolutions per unit of time ;

$p =$ pressure per square inch.

With given pressure and temperature the minimum value of the function $f \cdot a$ is determinable.

First, the pressure and the temperature which it is necessary to meet will indicate the density of the lubricant which it is necessary to use to prevent the surfaces coming in contact, and in the case of car lubrication will vary with the seasons of the year, causing a grading of the oils into those for summer, and lighter ones for winter service. Second, the value of a will depend upon the available space allowed for the journal. It will be seen further on that the results of the experiments indicate that the most economical conditions are obtained by increasing to within the practical limits the area and using a correspondingly lighter body oil for the lubricant.

The value of a for the most economical results is where any further decrease in the resistance by the use of a more fluid oil is counteracted by the resistance resulting from the increased surface. More explicitly, the experimental results would indicate that by reducing the unit pressure by increased area will allow the use of a lubricant of greater fluidity and a correspondingly less coefficient of friction. But in the case of a bearing upon a journal, it has been found that by increasing the arc of contact the additional surface obtained does not produce a proportionate decrease in the pressure. The pressure which must be considered the ruling one, and influence the selection of the lubricant,

is included within a small arc at the centre of the bearing. Practically, an arc of contact of some magnitude is necessary for strength and stability, and to also give a fairly large area to accommodate for the abrasion which takes place. The increase beyond this arc is only economical so long as the increased surface decreases the pressure carried by the centre arc to an extent that the lighter oil will, by the consequent reduction in the coefficient of friction, overbalance the increased resistance produced by a greater area. Assuming c as the constant and necessary arc of contact, and ω as the desired angle, it is not economical to increase ω when the expression

$$f\frac{\omega}{360} \times 6.282$$

is greater than

$$f'\frac{c}{360} \times 6.282.$$

f and f' indicate the coefficients of friction per unit of area for the lubricant which must be used to overcome the maximum pressure existing in the two cases which, in one sense, measures the fluidity of the lubricant.

An increase of the length of the journal seems to be advantageous provided it is not carried beyond the limits placed upon it by practice. The diameter of the journal is dependent upon its length and the load to be carried. Taking the usual expression for a beam supported at one end and uniformly loaded, we have

$$L = \frac{T\pi R^3}{8l},$$

where $T =$ safe ultimate load for the metal, and the other symbols indicate the same as in previous formulæ.

For the deflection we have

$$d = \frac{Ll^3}{2\pi R^4},$$

where d represents the deflection. All are indicated in pounds and inches.

The formula for the variation of the diameter for changes in the length will be used again.

CHAPTER III.

COEFFICIENT OF FRICTION.

WITH the exception of the method of lubrication, there is no other element in connection with the subject under consideration that has received more attention than that of the coefficient of friction, and yet there is no other that is in as crude and indeterminable a state. As investigation progresses, the subject seems surrounded with more and more variables of a complicated nature which indicate the importance, if not necessity, of the utmost refinement when the best results from lubrication are desired.

The latest study of the subject has brought out some very interesting results, and has conclusively shown that it is now necessary to at least limit the old laws of friction to dry surfaces in contact, if not exclude them totally. The resistance of friction, when a medium is introduced between the so-called rubbing surfaces, follows laws quite different and more intricate than those determined by Morin, which were to the effect that "friction was independent of the surface in contact, but directly dependent upon the pressure keeping the surfaces together."

Where friction is produced it is important to distinguish between the two conditions to which the two sets of laws apply; in one it is a solid against a solid, the particles of each interlapping and causing resistance by

the efforts of the particles of one metal to tear away those of the other. Where lubrication is introduced it is intended that the two solids shall be separated by a film of the lubricant, generally a liquid. In this latter case the resistance assumes the nature of the laws of fluids, and consists of the friction of the particles of the lubricant and that of the solid against the fluid, forming a combined resistance, the percentage of each of the whole retardation depending upon the nature of the lubricant and the metal surfaces. As long as the metals are prevented by the lubricant from coming in contact, it is found the friction is dependent upon the fluidity of the lubricant, and varies with changes of this fluid condition, decreasing with a higher temperature and increasing with a less degree of heat.

We will assume, first, that the lubricant in all cases prevents any contact of the metal surfaces. The condition then stands between the laws of solid friction on the one hand,—friction independent of the surfaces in contact, but dependent upon the total pressure,—and the laws of friction of liquids on the other,—that friction is independent of the pressure per unit of surface, but is directly dependent upon the extent of surface and increases as the square of the velocity. From most recent investigation this intermediate condition has been found to be, when stated in a general way, that the coefficient of friction decreases with an increase of the pressure, although the total resistance rises directly but not proportionately with the higher unit pressures and increases with the velocity, although not as rapidly as its square. It is also found to be dependent upon the extent of surface in contact. An exact

relation between these varying conditions has not yet been obtained, evidently because they vary so materially with any slight variation in the method used of lubricating the surfaces. As, for instance, when the oil bath is used the laws of lubricated surfaces, especially as regards surface and pressure, follow those of liquid friction very closely; while with less efficient means of lubricating the results give a more intermediate result between solid and liquid friction. This matter will be brought out more prominently in the chapter on the methods of lubrication.

With the surfaces in good condition and the oil-bath method of supplying the oil, which may be considered as practically perfect lubrication, it was found that the mean resistance per square inch of surface with pressures varying from 100 to 310 pounds per square inch was as follows:

Lubricant.	Mean resistance in pounds.
Sperm oil	0.484
Rape oil	0.512
Mineral oil	0.623
Lard oil	0.652
Olive oil	0.654
Mineral grease	1.048

[Results obtained by Tower.—See *Engineering* for November 16, 1883, and February 6, 1885.]

The speed was 300 revolutions per minute, and journal four inches diameter and six inches long, while the temperature was maintained at 90° Fahrenheit.

A constant temperature is essential for a proper comparison, as in one case with lard oil the coefficient of friction decreased to one third ($\frac{1}{3}$) its value at 60° by an increase to 120° Fahr., in the temperature of the lubricant.

Probably the most accurate laboratory experiments made for the determination of the resistance of lubricating oils were those made by Woodbury for the North Eastern Cotton Manufacturers' Association as published in their Proceedings of April 28, 1880, and in the Proceedings of the American Society of Mechanical Engineers as contained in volume VI. They were made with the object of appropriating the results to cotton and woollen machinery where low pressures are used, and to that extent are not well adapted to the lubrication of car journals excepting as showing the action of lubricants under varying conditions of temperature and a limited range of pressure. They were presented about the same time as were the results of Mr. Tower's experiments, the latter, however, under heavier pressures, but both clearly showing the different conditions under which friction must be studied when solid surfaces are lubricated by such bodies as the mineral and animal oils. It was found in the tests that uniform results could not be looked for unless constant temperature, velocity, pressure, area of surface in contact, and thickness of the film of the oil between the surfaces were maintained, the latter depending somewhat upon the method of lubrication, indicating at once that the resistance of friction was dependent upon and changed with a variation in any of the above conditions. The metallic surfaces were cast iron and bronze, the latter composed of copper 32, tin 2, lead 2, and zince 1. In one case all conditions were kept constant excepting that of pressure, the diagram represented as Fig. 3 indicating a decrease in the coefficient of friction, but an increase of total resistance. Similar tests were made,

keeping the pressure constant and varying the temperature, which gave the effect of the variation of the temperature upon the coefficient of friction.

The two diagrams, Figs. 3 and 4, indicate by the two curves the variation which takes place in the coefficient of friction under the varying conditions.

In Fig. 4 it will be noticed that the variation in the coefficient of friction due to changes in temperature follows closely the laws of the straight line indicating a proportionate decrease with the increase in tempera-

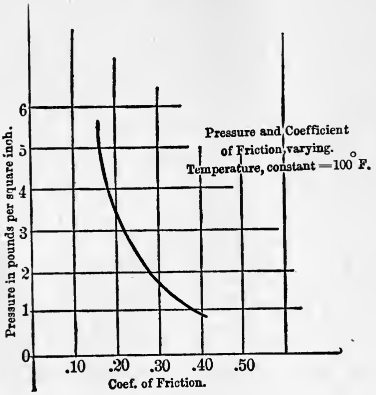

FIG. 3.

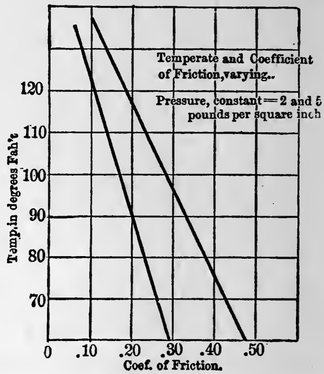

FIG. 4.

ture; the angle of the line with the abscissæ depending upon the pressure per square inch.

Combining these two diagrams gives a curve for the coefficient of friction as shown in Fig. 5, where the two variables, pressure and temperature, are considered, and it is this relationship which most concerns the lubrication of surfaces such as car journals. In that practice, the temperature is subject to changes occurring from changes of seasons and weather, while the pressure carried per square inch is dependent upon how long

the bearing has been subjected to wear and attrition, the unit pressure decreasing with increase of service. While the results obtained by Woodbury are the most accurate that have been published and probably ever made, both as regards design of apparatus as well as its manipulation, there still lacks sufficient uniformity for the derivation of a definite law as to the variation of friction with changes in temperature and pressure.

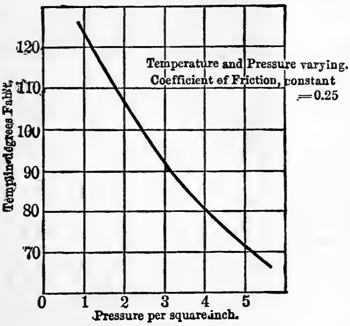

FIG. 5.

NOTE.—The coefficient of friction in the three cases is represented in actual pounds resistance.

For instance, the decrease in the coefficient of friction as given in table below for pressures of from one (1) to five (5) pounds per square inch is:

Pressure per square inch. Pounds.	Coefficient of Friction.	Decrease in Coefficient of Friction.	Difference in the amount of decrease.
1	0.3818	0.0000	0.0000
2	0.2686	0.1132	0.0000
3	0.2171	0.0515	0.0617
4	0.1849	0.0322	0.0193
5	0.1743	0.0106	0.0216

The decrease in the coefficient of friction from an increase of pressure of one (1) to two (2) pounds was

0.0617 more than that from two (2) to three (3) pounds, while the increase from three (3) to four (4) pounds was 0.0193 and nearly the same as took place when the pressure was increased from four (4) to five (5) pounds.

The above is cited more to prevent a deduction of too wide a nature rather than to deter from the gratitude which the engineering profession must feel for the derivation of the general law of the variation of friction with lubricated surfaces when the temperature and pressure are varied. The care which it was necessary for Mr. Woodbury to exercise to obtain these results can be appreciated when it was found essential to run the apparatus, using gasoline or its equivalent, to clean an oil from the surfaces after testing. It required a travel of one surface over the other equivalent to about forty (40) miles before it was advisable to commence the trial of the succeeding oil, and even then indications could be noticed in the test following of the properties of the oil previously tried. This is considered further evidence that the friction of lubricated surfaces is made up of the friction of the fluid and tends to prove that the lubricant embeds itself into the surface of the metal, producing a fluid resistance rather than a resistance due to the rubbing of the surface of the metal upon the surface of the lubricant. This effect will be taken up again in the chapter on Bearing Metals.

The variation in the coefficient of friction with changes of temperature is readily carried to an extreme, as it has been found that while the resistance decreases as the temperature is raised, there is a point, depending upon the unit pressure and viscosity of the

lubricant, where the coefficient starts to increase very rapidly with increase of temperature. The same holds true with a variation in the pressure; and while the laws of changes are true as stated, in a general way, they depend and are limited by the viscosity of the lubricant used, and also the pressure which it is necessary to carry. The rapid increase, when the limits of temperature and pressure are exceeded, is due to the solids coming in contact and causing increased friction by the abrasion of the surfaces, reducing the condition from friction of fluids to that of solids.

An attempt has been made to prove a positive relationship between the viscosity of an oil and its coefficient of friction; and while they are, no doubt, more or less dependent, there are hardly sufficient accurate data at hand to make the relationship a positive one and free from the possibility, if not probability, of a more or less dependence of friction upon a property which might be termed unctuousness in addition to that of viscosity. It appears, and there seems sufficient information at hand to anticipate it, that a relationship of a positive and determinable nature between the three elements, coefficient of friction, viscosity and unction, is obtainable.

The results of the experiments made by Mr. Tower, as presented before the British Institute of Mechanical Engineers, are of such a nature that they can readily be converted into practice with a resulting profitable application. They go to corroborate, to a close degree, the results of Mr. Woodbury, although they have the advantage of having been made with higher pressures. It should be remembered that with high pressures,

such as those obtained before seizure takes place, the film of oil separating the bearing and journal has been found to be as small as 0.05 of an inch, which would indicate the result that may be expected with a bearing where the irregularities or projections on the surface of the journal or bearing are greater than the thickness of the film of oil used to separate them, producing when in motion a rapid and detrimental abrasion of the metals with a marked increase in the friction. It would not be safe to allow particles to project from the surface more than 0.05 of an inch—unless, of course, the prevailing area is of this height. The other extreme, of having the surfaces too highly polished, must not be selected, as it has been found that a moderately rough machined surface will carry something like seven (7) times more pressure before seizing than can be obtained from highly polished surfaces. The proper condition would seem to be about that produced by a boring tool, except with the soft metals, which from their nature are incapable of taking a high polish.

For the purpose of comparison, let us consider briefly some of the results obtained by Mr. Tower where the journal was lubricated by the oil-bath method and the surfaces were in good condition. Assuming a loaded car of total weight of 80,000 pounds would give 10,000 pounds per journal. At a pressure of 300 pounds per square inch this would require a bearing area of 33.33 square inches to carry the load. With the resistance given for mineral oil of 0.623 pounds per square inch and a journal of 4 inches and a wheel 33 inches in diameter, a tractive resistance of 2.52 pounds per journal or of 0.504 pounds per ton would be re-

quired after motion had been produced. With the latest dynamometer readings the resistance of journal friction for loaded cars will probably reach as low a figure as 2 pounds per ton on level tangent when running at a speed of 15 miles per hour. Retracing, this figure gives a journal resistance of 82.5 pounds and as high a figure as 2.48 pounds per square inch of bearing contact. It will be seen how low an efficiency is obtained in practice; but it should be remembered that the above laboratory tests were with the oil-bath method of lubrication, which has proven, when so tried, to be far superior to any other method that is at present known for lubricating surfaces. In most cases it has been found that the resistance of friction is a direct proportionate function of the area of surfaces in contact; twice the bearing surface, all other conditions remaining the same, will give, approximately, twice the resistance from friction.

The information as presented by the theoretical tests of oils is of much importance in the selection of the ones best suited for the conditions of the particular service. The conditions here met are not, however, such as will allow the delicately calculated conditions of a constant relationship of bearing surface, lubrication, temperature, and pressure, but require a large factor to be used to cover the variation which takes place in the service. For instance, when starting with a new bearing, the surface in contact is much less than when it has worn down to a point where the whole arc of contact has been obtained. This is one of the conditions which must be met, for with the irregularities of the parts accompanying the distribution of the load it is found,

excepting with the so-called soft-bearing metals, that heating will almost invariably result if the bearing is fitted to the journal throughout the whole arc which it is capable of including. There seems to be a binding action on the journal. If the bearing is so fitted as to allow a small amount of motion, the wear will take place in a manner consistent with the alignment of the journal-box. The variation in the unit pressure is not, however, as wide as would at first be supposed, as will be seen on reference to Chapter II, where the variation in unit pressure due to changes in arc of contact are given. The viscosity of the oil selected should then be such that it would keep the surfaces apart under the conditions of minimum arc of contact, and at the highest temperature that will be met. This temperature is not dependent altogether upon that of the atmosphere, but, on the contrary, will vary much with the nature of the service. For instance, with long, continuous fast runs the temperature of the journal will be considerably above that of the atmosphere. With this service, the heat arising from the work of friction will be such as to raise the temperature of the journal and bearing before a constant condition is reached. The conductivity and radiation of the heat through and from the surfaces is not sufficiently rapid to accommodate for all the heat generated. It will not be found uncommon for journals in severe service to reach a temperature of a hundred and fifteen (115) degrees Fahr. with the atmosphere only 50 to 60 degrees. This is to the advantage of the lubrication, provided an oil has been selected with sufficient body to meet the conditions. If such has not been provided, the parts

are reduced to such a sensitive state that the slightest cutting from the entrance of foreign matter between the bearing surfaces is apt to result in an overheated journal, or what is generally known as a hot box. The maximum pressure per square inch that must be sustained without seizure at the highest temperature that will be reached will determine the grade of the oil which it will be necessary to use. The resistance is a minimum when the product of the coefficient of friction into the area in contact is a minimum. When the limitations of the case require the use of high unit pressures, correspondingly heavier oils must be used to prevent the bearing seizing the journal; but that oil, all other variables remaining the same, which will give the lowest coefficient of friction and prevent the surfaces coming in contact is the one to be used.

The work done is dependent upon the circumference of the journal, so that any change in the diameter of the journal affects correspondingly the work of friction. The diameter of the journal varies as $3.175 \sqrt[3]{l_1}$. The work of friction is dependent upon the coefficient of friction per unit of surface, the area in contact and the distance travelled; or, depends upon

$$W = 3.175 \pi afn \sqrt[3]{l_1}.$$

The variation in the diameter is that necessary to maintain strength for the changes in the length. Referring to the table on page 14, we are enabled to infer as to what are the intrinsic values of the heavy and light oils upon the resistance due to the work of friction. For instance, Tower found that with rape-seed

oil the pressure which it would resist up to the point of seizure was 573 pounds per square inch, and with mineral grease a pressure of 625 pounds per square inch. To make a comparison between sperm oil, which is of still lighter body, and mineral oil, we would have, assuming a proportionate power of resisting pressure, of 541 pounds pressure as the capacity of the sperm oil. Taking this oil, and with a bearing surface of $1\frac{1}{2}$ by 8 inches, we find it would require for mineral oil $\frac{1\frac{1}{2} \times 8}{x} = \frac{625}{540}$ or 10.4 square inches of surface to sustain the load. The corresponding length would be 6.9 against 8 inches with sperm. The expressions for the work of friction in the two cases would be

$$W = 3.175\pi\, afn \sqrt[3]{l_1};$$
$$W_1 = 3.175\pi a'f'n \sqrt[3]{l_1'};$$

and their ratio

$$= \frac{fa \sqrt[3]{l_1}}{f'a' \sqrt[3]{l_1'}} = r.$$

$$f = 0.484, \quad a = 12, \quad l_1 = 8;$$
$$f' = 0.623, \quad a' = 10.4, \quad l_1' = 6.9;$$

$$r = \frac{112.73}{123.75} = 0.911.$$

It is very evident from these figures that the heavy oils, even with the decrease of bearing surface which they allow, are not as economical as the lighter ones, so that the work of friction is least where the limitations are such that they will allow an increase in the length of journal, resulting in an increase of the bearing surface, when an oil of light body may be used.

This conclusion has, of course, its practical limits, as well as modification by results of the resistance value of oils from more thorough experimental results. By again referring to the table, it will be found that the values of the mean resistances per square inch are for pressures varying from 100 to 310, while the resistances for several values between these limits would be of invaluable assistance where results between these limits are desired.

CHAPTER IV.

BEARING METALS.

THE questions of oil and bearing metal, in their relation and application to car lubrication, are capable of almost indefinite treatment, so much so that it has now become the work of a specialist to properly follow each and advise as to their efficiency. The adulteration of oils made them a subject of suspicion and necessitated rigid specifications and inspection to eliminate the probability of such deterioration. This having been successfully accomplished, through proper specification and inspection, the next point is the selection of the oil best suited for the journals to be lubricated. This requires the consideration of properties in addition to that of their coefficient of friction. These are such as the rate of evaporation at the working temperature, the tendency of spontaneous combustion from the evaporation, the decomposition of the oil by the atmosphere, and, still further, that of the chemical action of the acid,—which animal and vegetable oils contain to a greater or less extent,—upon the metals used for the bearing.

For instance, an oil whose exposed surface gave an evaporation of 20 per cent would be far inferior to one which gave but 10 per cent evaporation at the same temperature and in the same time. It is also objec-

tionable on the ground that the oil giving the higher evaporation would also be more liable to give trouble from combustion arising from the rapidly vaporized oil. Care must be taken not to conflict the flashing point with the rate of evaporation, as they are not in any way relevant, for it has been found * that, in one case, two oils having the same flashing point gave the rate of evaporation of 9.4 and 24.6 per cent respectively. When determining the percentage of evaporation of oils for comparison, the surface, time, and temperature should be the same in all cases, as otherwise it would not be a true comparison. The mineral oils have a low evaporation, and when mixed with those of an animal and vegetable nature prevent, to a large extent, the spontaneous combustion which is otherwise apt to arise and give trouble when the latter are used alone. The chemical effect arising from exposure to the atmosphere is of much importance in its influence upon the lubricating value. This action, with the fine particles of dust or foreign matter which enter through the front and back of the box, reduces the top of the waste to a pasty condition which materially depreciates it as a lubricant. It should be remembered that the result obtained from the use of mineral with the animal oils is dependent upon their relative proportions and the temperature to which the mixture is subjected. The use of the petroleum products has a remarkable effect toward reducing the tendency to inflame so common with the animal and vegetable oils when used alone. The relative value

* See Prof. Ordway, in Proceedings of Semi-annual Meeting of N. E. Cotton Manufacturers' Association held in Boston, Oct. 30, 1878.

of oil from the standard of percentage of evaporation and inflammability is unknown; in fact, it is as yet an undeveloped field, but represents properties which must sooner or later enter as factors in the efficiency of an oil for lubricating purposes. The importance of these will be appreciated from the results which Ordway found, where with one oil the evaporation in twelve hours at a temperature of 140 degrees (Fahr.) was 24.6 per cent.

As well, too, should the question of the chemical effect of the acids in the oil be taken into consideration. For these two reasons the mineral oils are coming into general use for car-lubricating purposes, while they also give, from their lubricating qualities, as low a coefficient of friction as any of the animal or vegetable oils. They can be obtained of almost any desired gravity and fire test, and, when clean, are particularly well adapted to the service in question.

The brass-foundry practice of to-day is still so much dependent upon empirical laws that it is impossible to form any definite or concise conclusion as to the exact nature of the alloy, all things considered, which gives the best results for car bearings. So much depends upon the foundry treatment that a chemical analysis is of very little value from which to draw any definite conclusions as to the nature of the service which a known mixture of metals will give. The same ingredients differently treated will give alloys of marked variation in their physical properties, and until the foundry working can be reduced to a more accurate science we must be subjected to the so-called kinks which have in some cases produced metals of remark-

ably good wearing qualities. This is illustrated in phosphor bronze, where the metal as produced contains about 0.75 per cent of phosphorus, while about one (1) per cent was used during the treatment.

The effect of the phosphorus is to produce a more solid casting by reducing the amount of oxidation which takes place during the mixing of the metals.

The metals used for bearings may be classed about as follows: phosphor bronze, brass, and the so-called white metals, the latter containing a large percentage of lead, zinc, tin, or antimony, with but little or no copper.

Each has a wide range of hardness, but from all that can now be gathered the white metals give excellent service and wear less than the harder alloys. In 1883 the writer had an excellent opportunity to compare, in a general way, the service of a hard bearing with one composed of antimony and lead—the latter material was run into an iron shell. The two roads were located in the same country and had the same destination and, as near as could be, the same service. The bronze required, as an average, a consumption of oil of 0.945 pound, and the white metal an oil consumption of 0.3075 pound, each, per car per 100 miles. Where the bronze was used it was necessary to resort to lard oil, making the cost per car per 100 miles in the two cases 6.3 and 0.88 cents respectively.

The white alloy was remarkably free from heating, while with the bronze bearings hot journals were giving continual annoyance.

As regards the wear of the soft and hard metals, the experience with bearings lined with lead alone indicates

the remarkably long service which can be obtained from even a lining but $\frac{1}{16}$ of an inch thick. Experiments as given in the *Railroad Gazette* for March 5, 1886, are much in favor of the white metals.

There is some difference of opinion as to the resistance of friction with the two alloys, as well as their effect upon axle wear, neither of which points has, as far as known, been proven to a satisfactory conclusion, and the field of the determination of the best wearing metal is open to valuable research. As regards axle wear, however, it will be seen, by reference to the chapter on the cost of lubrication, that bearing metal and axle wear are almost equal in value for the loss resulting from abrasion per 1000 miles. With soft and hard metals moving together the result is always a more rapid abrasion of the harder one. This is where the surfaces are separated by a grinding material; but when properly lubricated the condition is quite different, as then the separating material is fluid and slow in its wearing action; and, from the experience of those who have the white metal in general use, the wear is not increased by the particles of dust which its opponents claim become imbedded in the bearing, and in that way exercising an additional grinding action upon the journal and increasing the wear over that produced by the harder metals.

While there seems no reason to expect a more rapid wear of the journal from the softer metals, yet it is a subject seriously affecting the cost of lubrication and one upon which there lacks sufficient information to warrant the positive assertion that the softer metals are superior to the harder ones for bearings. Experience

so far, however, seems to be in favor of the white metals.

There has been a tendency to attribute the metal contained in an oil that had been in service to the wearing of the bearing, but the experiments of Volney will show the relative action of different oils upon the decomposition of brass. The figures also represent the values of the oils in this respect, and, together with the oxidation which results from exposure to the atmosphere, would indicate their influence towards producing the pasty condition of the waste. The dissolving power should act in its relative importance for the selection of the oil that is to be used. It would also indicate that the percentage of the bearing metal found in the oil of a journal-box is not all due to abrasion.

From the fact that the mineral oils have less action upon the bearing metal and are less influenced by the atmosphere the comparison would still further corroborate the excellent results which can be obtained by the mineral oils when such are used for car lubrication. They maintain a more uniform condition than either of those of vegetable or animal origin.

Name of Oil.	Relative Dissolving Power.
Menhaden oil	0.511
Neatsfoot "	0.505
Olive oil	0.504
Crude cotton-seed oil	0.348
Lard oil	0.131
Crude petroleum from Scio	0.000

CHAPTER V.

METHODS OF LUBRICATION.

To persons unacquainted with the details of car lubrication there must appear a degree of scepticism far beyond that which seems reasonable. The devices that have been arranged and the so-called inventions that have been patented to lubricate car journals are innumerable, and yet there is not one at present in use that can be said to be in such a stage of developements as to be superior to the method of using cotton or woollen waste when this is properly arranged and manipulated.

The writer has had experience with numerous devices, most of which were arranged to lubricate from the under side of the journal. The nature of such devices was various; some were made up of a revolving cylinder in contact with the under surface of the journal, while the lubricating mechanism ran in oil. The roller, when such is used, receives its motion from the journal in which it is kept in contact by a spring or some similar arrangement. Devices of this general nature have been made in numerous quantities, all differing only in some minor detail. None of them have been known to produce satisfactory results. Mechanical methods in the nature of pads kept in contact with the journal by spring have been tried, but from a thorough trial the results seem to indicate that the elasticity

of the waste commonly used is superior to the mechanical devices, not only in the quality of the lubrication, but also in the mileage rendered. One case is known where an attempt was made to lubricate by feeding oil through the top of the bearing, and by waste at the bottom of the journal, similar to boxes used on foreign roads; and although the trial was of short duration, no apparent advantage over the generally accepted method were noticeable. Devices have also been attached to the front of the journal for lifting the oil to the bearing, some of which have proved fairly satisfactory. In fact, the possible methods of lubricating journals is innumerable; but with the mechanical devices, the objection which can be predicted to a fair certainty is the resulting failure from even a small percentage of breakage, while even their introduction to an extent to test this conclusion is a result as yet far distant, as no satisfactory method of this nature for lubricating a journal in an efficient manner is now more than in the experimental stage. We may except the so-called roller bearings, which have been tried with more or less satisfaction in an experimental way. The theoretical advantage arising by resolving the friction from that of sliding to that of rolling would appear to be a large gain; and yet from the experiments of Wellington (see Proceedings of American Society of Civil Engineers) it would appear this advantage is indicated only during starting, but is not so large a percentage gain after the velocity is increased. Roller bearings have been known to run successfully for 100,000 miles, but it is not known that they have been subjected, by a more general introduction, to an extensive

trial to determine their mechanical efficiency, such as wear and tear and comparison with bearing metal.

The results of Tower's experiments, previously referred to, give a close idea as to what is to be expected of the different methods of lubrication. It was found with three (3) methods of lubricating journals, feeding the oil from below and from above the journal, that the following ratios of their efficiencies may be expected:

Method.	Actual Load. Pounds per sq. inch.	Coefficient of Friction.	Comparative Friction.
Oil Bath....................	262	0.00139	1.00
Siphon Lubricator...........	252	0.00980	7.06
Pad under journal............	272	0.00900	6.48

The siphon lubricator was placed on the top of the bearing. The tests were under the same conditions. Rape-seed oil used. Journal, 4 inches diameter, running at a speed of 150 revolutions per minute. Temperature 100 degrees (Fahr.).

There can be no question, then, as to their relative efficiencies. The oil-bath method has had numerous trials upon car journals, but has always proved a failure from the difficulty of obtaining a mechanical means that would retain a tight joint at the back of the box unless it be made of such a complicated nature as to outweigh, on account of repairs, the advantages accruing from the method. The siphon method has objections on account of the high resistance offered, the cause for which will appear further on. It can safely be concluded that the use of a pad under the journal gives a higher resistance than would be obtained with what is known as waste, due to the closer texture

which its name implies. This gives it less power to absorb the oil, the importance of which is evident from the high efficiency obtained with the oil-bath method of lubrication. Two surfaces that fit tightly when dry can be made to move easily on one another by interposing a lubricant. It would seem, with the resistance arising from the tight fit when dry, that the introduction of additional material between their surfaces would offer still more resistance to their motion. The application is so common that the reason why it should be so is generally lost sight of. With this exceedingly thin layer of oil, whether in the nature of globules which have penetrated the pores of the metal, or a continuous layer of the lubricant between the surfaces, the result indicates the strength of the wedging action influencing the introducing of a lubricant between the metals in contact. This is quite the same action as when lubricating by means of an absorbent material saturated with the lubricant which is in contact with the lower side of the journal, unless the bearing grips the journal and scrapes the oil from the surface, in which case the object is defeated. With rolling friction, from the nature of the distribution of the load, it will be noticed by referring to Chapter I that the radial pressure upon the journal increases from zero, when the bearing includes a semicircle, to a maximum which is on a vertical line through the centre of the journal; that is to say, the nature of the distribution is such as to make the action the same as that of a wedge even when the bearing is in contact throughout the whole of its arc. It is an increase from a small to a large pressure

per unit of surface. The results of Tower are practical demonstrations of this effect. During the progress of the experiments with the oil-bath method of lubrication he had occasion to remove the bearing. It was then decided to insert a lubricator in the top of the bearing, for which a $\frac{1}{2}$-inch hole was drilled. After re-starting the experiments and before the cups were inserted in the top, oil was observed to rise in the hole which had been drilled, and was noticed to exude at considerable pressure, which, when indicated on the gauge attached to the top of the bearing, was found to be more than 200 pounds per square inch, while the average pressure (vertical) upon the bearing was 100 pounds per square inch. It was further found, when a groove was cut the whole length of the bearing and a lubricator attached to feed oil to this groove, that even with a pressure of seven (7) inches head of oil, it would not feed to the bearing, but, on the contrary, it appeared to be the means of escape for the film of oil between the bearing and the journal. When the cup lubricator was the only feeder, the bearing would not run cool with the pressure as low as 100 pounds per square inch. In this case, care was taken to chamfer the edges of the groove to prevent any scraping action. As the point of application of the lubricant was moved from a vertical towards a horizontal direction, the friction decreased and the bearing was found capable of carrying greater pressure before seizure. The experiments by Tower to determine the pressures at different parts of the bearing are so indicative of the wedging action which takes place that they are referred to somewhat in detail. The bearing was divided into

three (3) vertical planes lengthwise of the bearing, and each half into three (3) planes at right angles to the first ones.

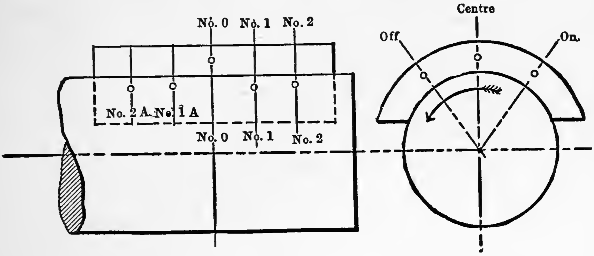

FIG. 5.

The lubricator was placed on the intersection of the planes passing through No. 0, No. 1, and No. 2, and the same pressures assumed for No. 1 A and No. 2 A —rather an unfortunate assumption, especially as the means of distribution may have had an effect upon the pressure at the points on the rear half of the bearing. The results were as follows :

Longitudinal Planes.	On.	Centre.	Off.
Transverse Plane No. 0....	370	625	500
" " No. 1....	355	615	485
" " No. 2....	310	565	430

The figures represent in pounds the pressures per square inch. The bearing had a total load of 8008 pounds, the journal running at a speed of 150 revolutions per minute. Temperature constant at 90° (Fahr.). Journal 4 × 6 inches.

The maximum pressure is at the centre, as was to be expected ; but the increase on the off side of the bearing would go to indicate that the wedging action is so dom-

inant as to actually skew the bearing on the journal, and would do so where there is clearance between it and the sides of the box to allow of any such motion. That such results are shown by experiments which contradict the more or less satisfactory practical use obtained when surfaces are lubricated from the top can be attributed only to the effect of the end play of the bearing on the journal, and to the change in position when the bearing and journal are not as closely fitted as was the case with the apparatus which Mr. Tower used and which was probably necessary for the nature of the tests which he made. It then becomes apparent that the method of oiling from the under or exposed part of the journal is by no means the most inefficient one, but, on the other hand, seems to be the best way of introducing the lubricant. Inasmuch as the oil-bath method has been found impracticable, the result obtained by it is a favorable indication to the now generally accepted plan of using waste saturated with oil. To obtain the very best results in this way, however, it is necessary to observe a number of the details of the method. For instance, when using new waste it is important, in fact necessary, to thoroughly saturate it before placing it in service, the importance of which is probably sufficiently indicated from the following experiment. It was the practice to oil journal-boxes of passenger-equipment cars at the end of each of the sub-divisions of a through line with the object of preventing the occurrence of heated journals and assuring the condition of good lubrication. To test the necessity of this method a car was selected the journal-boxes of which were carefully cleaned and repacked with new waste which had, for

some few hours before, been thoroughly soaked in oil. For some two hundred miles of the run after repacking, the journals were very warm and had almost reached the point where scaling of the surface of the bearing takes place. No oil was placed in the boxes, however, especially as it was found that the journals seemed to become cooler as the distance run was increased. The car was taken some four hundred and fifty (450) miles, when the journals were very cool and reached their destination in good condition. The car was returned to the starting point, and it afterwards made a second round trip, covering in all eighteen hundred (1800) miles with one oiling, and yet at the start it seemed as though the car would not succeed in covering more than one hundred (100) miles before trouble would arise. The warm condition of the journal and surrounding parts increased the fluidity of the oil and apparently enabled the waste to more easily absorb it and exercise its capillarity. That the waste at the end of the second round trip was still in good condition partly indicates what can be accomplished by systematic attention, although the trial does not indicate a successful but rather a dangerous way of saturating the waste. It is cited to emphasize the importance of having the waste well saturated before placing it in boxes. In a short paper read by the writer (see Proceedings of Engineers' Club of Philadelphia, fall of 1886) there is given the result of a crude experiment made with the object of roughly determining the absorptive powers of fibrous and woollen waste. A small quantity of dry woollen waste was taken, one end of which was placed in a large cup half filled with oil, and the other end,

after passing over the top of the cup, was allowed to pass down the outside and rest upon a table. After standing some twenty-four (24) hours, the waste was oily to the touch and a small oil-spot was found upon the table. The waste was allowed to remain in this condition for some two (2) or three (3) days, but seemed to absorb but little if any more of the oil, indicating the almost inconsiderable effect of capillarity in comparison with what is already known as its absorptive power. When the best results are desired from this method of lubrication, the necessity of thoroughly saturating the waste, that is, covering it with oil for some days before using, becomes apparent. The object should be to produce with waste, as near as can be obtained without incurring the loss resulting from splashing, the condition known as the oil-bath method of lubrication. To obtain such a result we cannot depend much upon the capillarity of the material. The condition to give this end, it seems, should be to obtain a state of saturation such that the journal is continually replenished with oil as it revolves. The degree of saturation will decrease from that at the bottom of the box to the top of the waste. The top of the waste should contain an amount of oil just below the state where it will run from the back or front of the box, hence the advisability of having these points oil-tight; they not only reduce the loss of oil, but also render a lower resistance from friction. The small amount of dependence which can be placed upon capillarity can also be tested and proved by an examination of the waste of a journal-box which has been in service some months. That at the front will be found to be

much better saturated with oil than the waste at the back of the box. For this reason it is thought the oil should be introduced into the box at some point about midway of the journal, which can readily be done by small openings in the front and leading back by cored passages to any point where it is desired to bring the oil in contact with the waste.

CHAPTER VI.

JOURNAL-BOX CONSTRUCTION.

JOURNAL-BOXES have been made in numerous ways, in some cases all the attention having been given to the exclusion of dust at the rear of the box, as the most important constructional feature, while with others, to facilitate oiling and at the same time make a dust- and oil-tight joint, the study has been given to the opening at the front of the box.

The distribution of the load, however, seems to have received less attention than either of the two preceding. It is unnecessary to give a historical review here of the numerous devices which have been tried to make the box dust- and oil-tight; but suffice it to say that efficient means to accomplish these results, especially for the back of the box, are too much overlooked. A good dust-guard seldom proves a bad investment; it should, however, be simple in design and of a material that will not be affected by the oil used for the lubrication. It should also accommodate itself to the wear of the bearing.

The method of distributing the weight upon the bearing is an interesting analysis, and, if not carefully followed, will produce results from which considerable trouble may arise. From the conditions of the case it will be well understood by those at all familiar with

the design and nature of the mechanical appliances used for carrying the weights of cars that mechanical accuracy in the parts cannot be obtained. Especial reference is made to the condition of the seat in the top of the box and the top of the bearing, both of which are rough castings, and, however clean and accurate these may be in the rough, it is impossible to obtain a condition for the distribution of the load such as can properly be expected from finished surfaces. In one of the designs which has come under notice the weight was thrown on the centre of the bearing, as shown in Fig. 6. Notwithstanding the bearing-metal

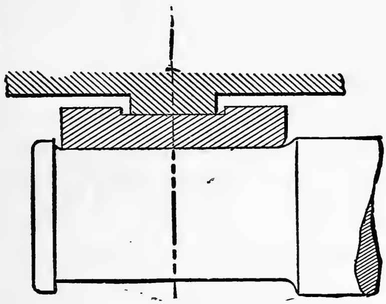

FIG. 6.

was as strong as any known to the trade for frictional purposes, the test of this design, after some years of service, gave positive and decided indications of hollow-worn journals, due to the springing of the metal at the ends, as would naturally follow from such loading. Fig. 7 indicates the result, exaggerated, to which reference is made. It may be properly inferred that to obtain sufficient strength of the bearing to prevent such a wearing result of the journals would require a thickness of metal much greater than when the distribution

of the load is more even or uniform. Other objections to this increase of the weight of the bearing will be indicated in the chapter on the Cost of Lubrication.

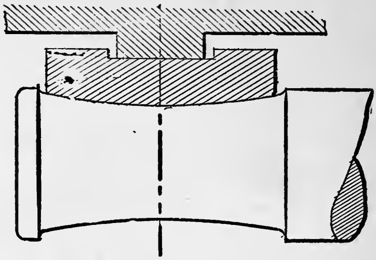

FIG. 7.

The prevailing practice in the distribution of the load upon the journal is that shown in Fig. 8, where, on paper, the weight is uniformly distributed over the whole top surface of the bearing. The practical operation, though, is quite different from this, as will be readily seen by an examination of journals which have been used in this design of box. Instead of

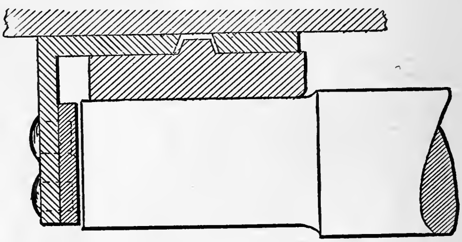

FIG. 8.

a uniform wear, it will frequently, if not generally, be found that the journal is worn small either toward the inside or outside end, showing conclusively that the weight is thrown most prominently in either of

these two directions. An analysis of the conditions will give sufficient cause for this result. The design indicated by Fig. 8 is that used by a number of the systems, and as regards the distribution of the load it will illustrate the general principle which is now extensively introduced in railroad work for this purpose.

When all goes well, uniform wear of the journal can be safely looked for; but when considering that the top of the bearing is an unfinished casting, it is not surprising to find the load actually taken as illustrated by

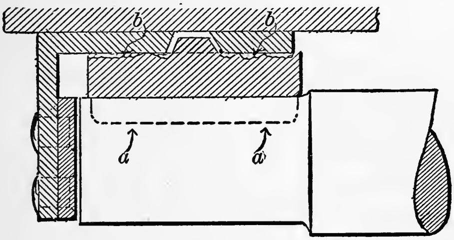

FIG. 9.

Figs. 9 and 10; the conditions shown in Fig. 9 illustrating the effect of irregularly distributed high spots.

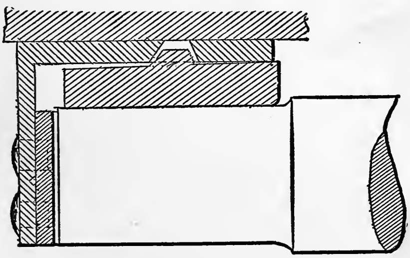

FIG. 10.

That shown in Fig. 10 may arise from one of two causes: 1st. When the top surface of the journal-box

is not parallel with the plane of the top of the bearing and the desired line of contact. This may arise from bad alignment of the box or lack of sufficient parallelism in the rough castings. 2d: From a journal worn small at the front end. It is evident that the positive prevention of the first of these influences would require a grade of refinement which present practice cannot meet.

When considering Fig. 9 it should be remembered that three (3) points determine a plane, the exaggerated roughness of the top of the bearing indicating a possible if not a probable condition. With this method of distributing the load, as the bearing is held during the boring by the top surface and the bottom edges, it is best to roughly dress these edges, *a*, *a*, making them parallel with the surface *b* so that the bored part will be parallel with the top.

The defective distribution of the load arising from lack of good alignment, and particularly irregularities in the rough castings, can, of course, be partly overcome by finishing the fitting parts, but involving thereby an expense which the conditions of the case would hardly warrant. It would seem, however, that by the method indicated in Fig. 11 the trouble would be alleviated without any increase in the refinement of the fitting parts. It will be noticed that provision is made to accommodate and meet the two prevailing objections to a good distribution of the load, and by finishing the edges, *a*, *a*, parallel with the top surface—the grinding of which is quite sufficient,—a more positively uniform equalization of the load can be obtained, and maintained with whatever changes may take place in

the position of the box. It will be noticed that the bearing is loaded similarly to the method shown in Fig. 6, excepting that it has less than half the length there indicated to influence the springing of the ends, which would not cause sufficient unequal wear of the journal to prove a practical objection. When carrying the load in this way it is not at all necessary that the top of the bearing should be parallel with the top line of the journal.

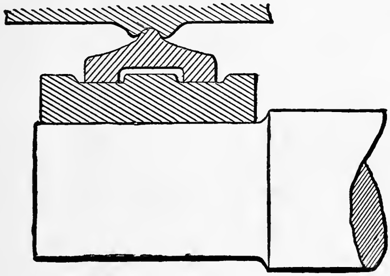

FIG. 11.

Much stress has been placed on the method of distributing the load, and it is very apparent that it is much influenced by the device used for transmitting the weight to the journal. Its effect is quite apparent in increasing the pressure per square inch on a small part of the journal, necessitating the use of an oil of higher resistance than might otherwise be used. More than this, the effect is to wear the journal unequally, and in that way render it unfit to receive a properly prepared bearing when it is necessary to renew one. As regards the latter objection, if the bearing and journal were of equal life, and considering only the condition after the bearing had worn to sufficient bear-

ing surface to carry the load without excessive abrasion and resulting heating, it would be of less importance as to how the weight was distributed; but when the journal, on an average, outwears some half dozen or more bearings, it becomes correspondingly difficult to renew the bearings without encountering considerable annoyance from the condition into which the journal has been worn by a load that has not been properly distributed. It is hardly strange that under such conditions delays from, and expense of, hot journals are encountered. It is rather surprising that they give as good a result as is now obtained.

With the object of meeting these mechanical defects, Hopkins applied a lining of soft metal, generally lead, to the under side of the bearing, by which it is enabled to adjust itself to unequally-worn journals and thereby rendering a larger surface for the weight than can be obtained when a more rigid metal is placed upon the journal. The arrangement, though patented at the time, was a most excellent one, and has given admirable results when properly applied to the bearing. It also assists in meeting the decrease in bearing-surface which arises when a new bearing is placed upon a much-worn journal. Care should be taken, however, to obtain the proper thickness of the soft metal lining; which has been found to be about $\frac{1}{16}$ of an inch. When more than this is used the lead is forced out at the edges of the bearing, and obstructs the free admittance of the oil between the surfaces, and in other ways produces trouble.

As the Hopkins patent has expired, a description of the way in which the lining is done may prove of

value to those who are anticipating the lining of bearings.

The operation is as follows: The bearings are first bored. As they are to be treated for lining, they are first placed on a coke-fire and allowed to become well heated, when they are cleaned with muriatic acid and tinned. They must then be warmed again so that the tin is in a condition for the lead to adhere to it. They are then placed on a mandrel to receive the lining of lead. The device for holding the bearings during the lining can be made of very simple construction. It should be so designed that the bearing can be clamped only central with the mandrel, which will make the lining of uniform thickness over the bearing. The radius of the mandrel should never be more than $\frac{1}{32}$ to $\frac{1}{16}$ of an inch of the radius of the journal which the bearing is to fit. The lead lining should never, however, be more than $\frac{1}{16}$ of an inch thick; and to insure this result, the mandrel for the particular diameter should be such as to prevent more than this amount between it and the bearing. The quantity of material to line bearings with lead, and the present market prices, are as follows:

TO LINE ONE HUNDRED (100) BEARINGS.

Material.	Amount in Pounds.	Cost in Cents.
Lead	60	285.0
Lead and tin for "tinning" (half-and-half)	4	70.0
Muriatic acid	0.4	0.6

The labor should not amount to more than two or three cents per bearing, as it does not require much skill for this work.

The value of this lining as a bearing metal has been stated at figures both high and low, but no reliable definite values are at hand.

As a soft metal, however, it will give excellent wear, which point has already been brought to notice in the chapter on Bearing Metal.

CHAPTER VII.

COST OF LUBRICATION.

THE representation of journal friction in actual dollars and cents is, after all, the important part of the question of car lubrication. It forms the goal to which the results of all the investigations in this branch are directed. The question is as to how many additional cars will an engine haul, or what reduction can be anticipated by the introduction of a new device, or a definite grade of oil, or, perhaps, a particular alloy for the bearing metal, in the cost of maintaining, satisfactorily, the lubrication of car journals. The efficiency cannot always, however, be seen in actual dollars and cents, without considering all the departments that are influenced. It is sometimes obtained through the reduction of anxiety of those in charge, by a lessening of the number of delays to trains, as well as a question of accommodation of the patrons. Considerable annoyance arises from heated journals, which are known to be expensive items of economy, if such can be, and is a true representation, when resulting from the use of ill-adapted or cheap material, or even of the design, of a small first saving with a large final expenditure.

Included in the cost of lubricating car journals, as now practised, is the wear of the bearing metal, quality and quantity of material used in applying the lubricant to the journal, the cost and amount of the lubricant, the wear of the journal, and, still more im-

portant, the cost of the resistance of friction as represented in coal consumption. Many of these variables are dependent upon the relative location of the line of the road to the supply markets, as also the current market prices of the articles needed, the importance of which is not to be considered here, but rather that of the efficiency of the mechanical parts. A combination of all these elements is obtainable, giving the resulting cost of maintaining the proper lubrication of car journals. This is also reducible to a condition representing the actual economy of oils of different quality and price, which material is varied and experimented with probably more than any other single one connected with the subject—probably, too, because it is the easiest handled.

To obtain an expression for the cost, let

$B =$ abrasion in ounces of metal per journal per 1000 miles run;

$b =$ cost of bearing metal per ounce;

$O =$ quantity of oil in pounds consumed per journal per 1000 miles run;

$o =$ cost of oil per pound;

$W =$ quantity of waste consumed in pounds per journal per 1000 miles;

$w =$ cost of waste per pound;

$C =$ coal required expressed in tons per horse-power developed;

$c =$ cost of coal per ton;

$A =$ wear of axle, diametrically, in decimals of an inch per 1000 miles run;

$a =$ cost of axle wear, including the item of labor for finishing, per 1000 miles;

J = journal resistance in pounds per ton of load;
T = load in tons per journal;
d = diameter of journal in inches;
d' = diameter of wheel in inches.

The horse-power developed due to journal resistance would then be, per journal per 1000 miles run,

$$\frac{1000}{60} \times \frac{d}{d'} \times \frac{J \times T \times 5280}{33000} = \text{horse-power.}$$

The cost of lubricating one journal, including the cost of overcoming friction, would be represented by the expression

$$2.667 \frac{d}{d'} \cdot CcJT + Bb + Oo + Aa + Ww = M.$$

If it is desired to compare two oils, there is but one item, that of the value of the waste, which can be left out of consideration. All the other functions enter as elements of the cost. The nature of the oil, however, would affect the wear of the axle and bearing, as well as the resistance from friction. The axle and bearing wear differs but little with two oils, unless there is considerable difference in their lubricating powers, so that, for comparison, the expression could safely be reduced to

$$\frac{M}{M'} = \frac{2.667 CcJT + Oo}{2.667 C'c'J'T + O'o'},$$

by which the relative value of two oils, M and M', would be determined. The object is to give, approximately, the values of the several functions entering as

elements of cost of lubrication, and from them to obtain some idea of what car lubrication costs when based on what is considered as average practice.

The coal consumption is determinable through the pounds resistance offered by the friction of the journal. It should be remembered, though, that it is pounds of traction, and when determining the coal consumed it should include the losses which take place between the boiler and the rear coupling of the tender. It is unfortunate that there is such a wide difference of opinion as to the pounds of resistance due to journal friction, a variation which could not be accounted for by the differences in the methods adopted by the various roads of lubricating journals. A close approximation for average service can be assumed, and a comparison can be made of the difference which would result from what may properly be considered about as wide a variation as takes place in practice. Most of the figures used are those obtained by different methods of testing, but the only true ones are those obtained from accurate dynamometer readings. The latest dynamometer diagrams show, with an engine of the consolidation type and with cars of 60,000 pounds capacity when running on a level tangent at a constant speed of fifteen (15) miles per hour, a resistance of $2\frac{1}{2}$ pounds per ton. This was with a heavy freight train, and the resistance would probably rise to $3\frac{1}{2}$ pounds per ton for lighter trains. Assuming the weight of the average freight train in the United States as 130 tons gives a basis from which an average figure can be obtained for the cost of overcoming the journal resistance. With an average car-load of 15 tons this would give $8\frac{2}{3}$ cars per

train of 130 tons. With cars having eight journals, this would give per journal a load of 3750 pounds. With 3 pounds resistance per ton would require, from page 20, 1.82 horse-power per 1000 miles run. This is for each journal, while the loss between engine and rear end of tender would be about 30 per cent. This would increase the power, when figured for the unit cost at the boiler, to 2.6 horse-power. With coal at $1.50 per ton on the engine, and a consumption of $4\frac{3}{4}$ pounds per horse-power, gives as average cost for the frictional resistance per journal per 1000 miles 0.926 cent. For comparison, let it be assumed that the oil selected is ill adapted to the purpose. For instance, that the conditions of the service are such that an oil of a resistance of 0.512 pound per square inch would be sufficient to meet the requirements, but in its stead one with a resistance of 0.652 pound per square inch had been previously selected and used. The cost per journal would then be 1.20 cents, representing an increase of over 27 per cent, indicating at once the advisability of selecting that oil which will give the least resistance, but which is, at the same time, capable of withstanding the maximum pressure obtained.

Considerable variation will be found in the oil consumption, due to the different service used for the comparison. With passenger trains the high speed requires a more thorough oiling to dissipate the large amount of heat generated by the resistance of friction. With such service this heat must be carried off much more rapidly than in freight service, where any surplus heating by friction, arising from grit or other foreign matter, has more time in which to allow

the journal to cool before reaching that state where the bearing and journal seize. In passenger cars the effect is quite different and requires means for absorbing in as rapid a manner as possible any surplus heat generated. It would then seem that the difference in the consumption of oil in the two cases has arisen, not from a desire or necessity to reduce the coal consumption, but rather to prevent the annoyance arising from hot boxes; and when this annoyance has been reduced or obliterated, it is too often assumed that the ideal condition of lubrication has been obtained. For instance, the oil consumption for passenger service has been known to be as high as 2.1 pounds per journal per 1000 miles, and as low, in the same service, as 0.55 pound. The first is an average condition, while the second is the case of a car that was being followed to compare the best results of woollen waste against a patented device, and indicates the possibilities in the way of oil consumption where closer attention or more systematic means are applied for lubrication. To further indicate the variation in oil consumption upon different roads, two lines were compared where the conditions of the service were as nearly equal as could be desired for a comparison. The oil consumption per journal per 1000 miles was, upon one, 0.354 pound and, upon the other, 1.05 pounds. From this, the difficulty of obtaining an average figure will be understood. We will, for an example and an approximation, assume it as one (1) pound per journal per 1000 miles in passenger service, and as 0.37 pound for freight cars. In the ratio of their relative mileages, this would give an average consumption of 0.5 pound

of oil per journal per 1000 miles. At $2\frac{1}{2}$ cents per pound, 1.25 cents would represent the value of the oil consumption.

When considering the question of bearings, a very pretty point of economy will be found. The nature of it is such that it can be and generally is overlooked, while its influence upon the cost of meeting this branch of the subject will be seen to be an important one and influencing quite as much the cost of the bearing as that of the metal abraded. It will be noticed that bearings are removed from service for two general reasons: first, where they are defective from overheating, or where they have become too thin from wear; second, from such defects of parts as require the removal of the axle. The second includes defective wheels or journals. In the first case the bearings may be fit for the scrap-heap but nothing better, while under the second heading the bearings may be comparatively new or but partly worn out. In fact, it will be found by an examination of a number of bearings removed from service, especially where the hard metals are used, that an average life of the bearings would not give more than from one half to two thirds their total wearing thickness as having been abraded before removal. The weight of metal remaining is seldom fit for further service, so that the loss, representing the difference between the first and the scrap value of the remaining part, must enter as an element of the cost of the abraded metal. For example, taking a bearing which costs to produce, labor and material, 16 cents per pound and weighing 10 pounds, would give as a total value of the bearing $1.6c. To compare extreme conditions, if

two ounces are worn away in one case and eight pounds in the other, the value of the abraded metal, rating the scrap as one half the original value, would be as follows: where two ounces is abraded, the value of abraded metal at $6.48 per pound, and where the eight pounds is worn away, a cost of 18 cents per pound. The latter would also give a greater average mileage per ounce of wear, as this becomes less rapid as the bearing becomes better seated to the journal. This is an extreme case, however, and in the absence of positive information we can safely assume, for approximate figures, the average condition as that where the bearing has worn fifty (50) per cent of its total weight. The first weight will be assumed as ten (10) pounds at a cost of sixteen (16) cents per pound. This would give the ounce value of the abraded metal as 1.5 cents. The wear per journal per 1000 miles is about 0.75 ounce, the value of which would be, on this basis, 1.12 cents. Objection may be raised to the rather low percentage of wear which is taken as the amount of abrasion of the bearing before removal from service, but it is thought that an examination of a number that have been reduced to scrap will be convincing. While the percentage of wear is low, it is not very far from the average results obtained. In fact, this point is such an interesting one that it is desired to continue it further. Take, for instance, the practice of using a cast-iron shell and filling it with a soft or so-called white metal. To eliminate the difference in the cost of the metal used for abrasion they will be assumed as of the same value, but instead of the bearing containing ten (10) pounds we will take it as consisting of seven (7) pounds of abrad-

ing metal, five (5) pounds of which, as with the solid bearings, is assumed as worn away before removal. The value of the abraded white metal would be 1.2 cents per ounce, and for the hard metal, as before, 1.5 cents per ounce. The cast-iron shells are practically indestructible. The cost of refilling a shell with soft metal would be less than the expense of moulding the hard metal in sand. To go still further, let it be assumed that both bearings, as ready for service, are of the same weight, and that the cast-iron shell of the one weighs three (3) pounds. Assuming the same weight added to the hard metal for strength, this would represent, with cast iron at two cents per pound and for an equipment of 50,000 cars, an increased capitalization of $152,000 more than where the cast-iron shells and white metal are used. It should be understood that this represents the increased outlay which is necessary for equipping with the hard metal bearings, but does not include the reduction of the value of the abraded metal, nor the less cost of preparing the shell with soft metal bearing for service. A more detailed comparison of the two kinds of bearings would show still further in favor of the soft metal, and the argument would indicate the advisability of such for car service. The so-called wedge or linen which is used over the top of the bearing in the Master Car-builder's design of box may be considered a step in this direction.

The wear of axles will depend much upon the service, whether passenger equipment of the different kinds or under freight cars; but when the axles are made of steel, and with wheels 33 inches in diameter, the wear is found to be about 0.0014 of an inch per 1000

miles. This figure is an average of a number of axles under passenger-equipment cars. Axles weigh some 375 pounds when-new, which, at a cost of 2 cents per pound, would be $7.50. Adding to this the labor of turning and preparing for service would make the first cost about $8.50. With an allowable diametrical wear or a diametrical reduction of one half ($\frac{1}{2}$) an inch reduces the weight of a 4×8 journal fifteen (15) pounds, and a scrap rate of one (1) cent per pound would give the value of the axle wear per journal per 1000 miles as 1.372 cents.

The quantity of waste required per journal-box averages 1.349 pounds, from which an approximate average of 30,000 miles is obtained, representing, at $8\frac{1}{2}$ cents per pound, $11\frac{1}{2}$ cents as the value of this material, to which should be added the cost of the oil used in saturating the waste, as this is generally thrown away with the waste when the latter is removed. The amount of oil necessary to saturate the waste for one box is 8.4 pounds, which, at a rate of $2\frac{1}{2}$ cents, would make the total for the waste and the oil $32\frac{1}{2}$ cents, or 1.083 cents per journal per 1000 miles.

To summarize we find as follows:

Per Journal per 1000 Miles.	Cost in Cents.
Coal required in overcoming journal friction	0.926
Lubricant	1.250
Bearing metal	1.120
Axle wear	1.372
Waste and oil used in packing boxes	1.083
Total	5.751

It should be remembered that the coefficient of friction and the consequent coal consumption are dependent

upon the nature of the service, and will be affected by a number of elements, such as the load carried, the nature of the bearing metal, and the oil, together with other minor influences which have been mentioned under their respective headings. So, too, the item representing the oil consumption is dependent upon the grade of such material, as well as what, in the judgment of the person in charge, is considered necessary for good lubrication; and is also influenced, to a large extent, by the design and degree of maintenance of the journal-box.

Lately there has been a tendency to substitute a 36-inch wheel for those 33 inches in diameter, especially in passenger service. The small additional cost, all of which is included in the increased weight of iron, is more than balanced by the less wear and tear of the wheel, resulting from a less number of revolutions, so that the work of friction can be considered as reduced to an extent equivalent to the proportionate increase in diameter. This would affect the coal consumption, together with the wear of the bearing and axle, in each of which a proportionate decrease can be looked for.

Per Journal per 1000 miles.—Wheels 36 inches diameter.	Cost in Cents.
Coal consumed in overcoming journal friction......	0.849
Lubricant..	1.250
Bearing metal......................................	1.027
Axle wear..	1.258
Waste and oil used in packing boxes.............	1.083
Total..	5.467

As regards lubrication, the 36-inch wheel is 5 per cent cheaper than one of 33 inches diameter.

CHAPTER VIII.

HEATED JOURNALS.

If a journal becomes overheated, it is positive indication that some part of the mechanism is out of order, just as with the human body any sickness is proof positive that one or other of the organs is not performing its proper function. The moral effect in the two cases is also similar; for no one points with pride, unless it be on a competitive line, to a car that is passing and leaving behind it a streak of red flame and heavy obnoxious smoke from one or more journals that have become hot.

It occasionally happens, and but occasionally, that journal-boxes receive too much care. This is apt to arise with trains in heavy service and in which delays attract unusual attention. With such trains it has been known that too much care has been used in the attention given to the boxes, especially in the too frequent use of new waste.

The examination of a bearing that has been removed from an overheated journal will seldom give sufficient trace of the cause. No attention should be given to the scaling found on such bearings, as it is simply a result and seldom indicates anything more than that the bearing has been in contact with the journal and heated by the friction so produced until the scaling resulted.

The cause of most of the hot boxes can be reduced to two general headings.

1st. Those produced by mechanical defects.

2d. Those due to defective lubrication.

The first is of such a nature that the construction can generally be analyzed and corrected. It may be in the design, such as the method of distributing the load, or imperfect dust and oil protection. Or it may arise from poor quality of bearing metal, waste, or oil. These as such require the proper course for their elimination, although a slow process, and sometimes an expensive one, where the lack of proportion or design is intricate. It sometimes occurs that the objectionable feature can be obviated by the expedient of some mechanical turn, such as using a lead lining where the load is not well distributed. One case is known where a re-designed journal-box which became necessary from more severe service gave a remarkable reduction of heated journals. The percentage of old and new journal-boxes in service was about in the ratio of four (4) to one (1); while the number of heated journals arriving at a specified point within a given length of time gave the respective ratio of one hundred (100) to three (3), giving a difference of ninety-seven (97).

Heated journals have been known to have occurred from a steady and heavy application of the brakes, referring to those applied by compressed air. When tracing this cause of heating it will be found that a new bearing, or one the radius of which is considerably larger than that of the journal, was used, and the amount of clearances between the pedestal, journal-box, and for the bearing is such that a slight raising of

the bearing results from the journal-box pressing heavily upon one side of it. In this way, the edge of the bearing is thrown against the journal, when all the pressure is taken by a very small area; and, if the brakes are kept on for sufficient time, more or less heating, but not always a severe condition, will result. It is not uncommon for heating to occur from the long fibres of new waste working between the bearing and journal, and especially before the bearing has worn down to its whole arc of contact.

Under the second head are included those arising from the use of poor quality of oil or waste and those that are due to improper attention. These arise from the lack of sufficient oil for lubrication, but more particularly where the waste next the journal has become so deteriorated from foreign matter or other means as to prevent good lubrication. The pasty condition of the top of the waste, more particularly where the animal oils are used, is also due to their oxidation and their effect upon bearing metals, the extent of which was indicated in the chapter on Bearing Metals.

The preventive for heated journals, coming under the second heading, would be a systematic method of attending to the lubrication. By this is meant that after the car had made a specified mileage, remove the waste from the boxes, which, instead of being thrown away, can be cleaned and thoroughly saturated with oil, when it will be ready to be again placed in boxes for lubrication. The important point is to break up the hard, gummy surface which forms on the top of the waste, and this can only be accomplished by removing the waste from the box. It is

probably safe to say that the method of attending to the lubrication of car journals on most if not all of the railroads of the country to-day is about as follows. The boxes are packed and oiled when the car first leaves the shop. After it is in service it is occasionally, or it may be frequently, oiled; by which is meant the front of the box is opened and a small amount of oil is poured in upon the top of the waste at the front of the box. The box is allowed to run in this way, and with the little additions of oil, until it is removed for one of three causes: a renewal of the bearing or of the wheels, or for a heated journal. The top of the waste in the mean time has become saturated with foreign matter, making a pasty condition which is aggravated where the animal oils are used on account of their oxidation, and probably more or less from the action of the acids upon the bearing metal. This condition of the top of the waste not only acts as a poor lubricant next to the journal, but prevents the oil at the bottom of the box from reaching the journal. Of the fresh oil poured into the box from time to time, a small part is retained by the waste, but a hasty examination will indicate that a large part is lost and thrown upon the ties. It has often been thought that a systematic method of removing the waste, so as to break this hard or pasty surface, would prove a very profitable investment. If the waste, after cleaning, contains too much grit or foreign matter to prevent its further use, let the oil, which in car service is never what is called worn out, be extracted from the waste and re-used, thoroughly cleaning it and straining to remove foreign matter.

Until more uniformity in the design of journal-box

and handling of freight cars could be obtained than now exists, the above would, of course, apply only to passenger-equipment cars.

It should be remembered that poor lubrication is represented in cost by actual dollars and cents, the extent of which is shown in the chapter on Cost of Lubrication, and the value of which is there shown to be of no small amount.

Like many troubles, a large percentage of the hot boxes could be prevented by the proper application of a handful of oil, provided such is done before the surfaces of the bearing or journal have become injured.

The present method of lubricating car journals is by no means an imperfect one when the best is made of it, and we should refrain from attributing the failures arising from a lack of proper attention to the method.